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MINERALOGICAL-STRUCTURAL FEATURES OF THE SEVRYUK STONY METEORITE

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MINERALOGICAL-STRUCTURAL FEATURES OF THE SEVRYUK STONY METEORITE */101

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The microstructural features of the Sevryuk stony meteorite, in its three color variants, are discussed. Predominantly elliptical chondrules, of both mono- and polysomatic types and mostly of olivine and rhombic pyroxene composition were found in all three variants. The quantitative ratios of minerals in the meteorite are tabulated, showing the presence of iron and troilite in the black variety and nickel-iron with an iocite shell in the gray types. The iocite content points to thermal metamorphism; the black and dark gray varieties are interpreted as modifications of the light gray type.

Author

1. Introduction

The Sevryuk meteorite fell on May 11, 1878 in the neighborhood of the village of Sevryuk in Kursk Oblast. Most of it is now in the Museum of the Kharkov State University, and a considerable part of it is in the meteorite collection of the USSR Academy of Sciences (Bibl.1, 2).

Three color varieties are distinguished in this meteorite: black, gray and light gray; they are sharply demarcated from each other.

Chondrules up to 2 - 3 mm in diameter are seen in a fresh fracture in the gray and light gray varieties of the meteorite. Against a dark background in a

* Numbers in the margin indicate pagination in the original foreign text.

fracture of the black variety, in some places, small segregations of ore minerals (nickel-iron and troilite), tenths of a millimeter in size, are observed.

2. Structure and Composition of the Chondrules

Under microscopic examination of the meteorite, chondrules and their fragments are observed in all three varieties. The chondrules are for the most part elliptical, less often spherical or irregular. Both monosomatic and polysomatic chondrules are found. Their mineralogical composition varies. Chondrules consisting of olivine and rhombic pyroxene are most frequent; chondrules with clinopyroxene and vitreous masses are less frequent.

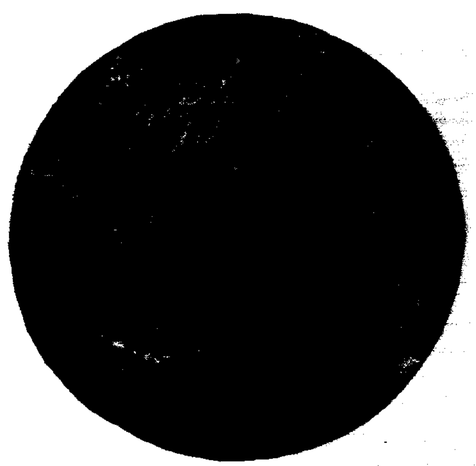

Fig.1 Chondrule of Eccentric-Radiate Structure and Pyroxene Composition.
Gray variety of meteorite. Section No.62.
Transmitted light. Without analyzer. × 100

In the gray variety of the meteorite, over an area of 110 mm^2, 42 chondrules were observed, and in the black variety, 36 chondrules over an area of 80 mm^2. Chondrules of spicular (barred) completely crystalline granular eccentric-radiate type are most often encountered, while chondrules of porphyritic and vitreous structure are less common. The outlines of the chondrules are not always sharp, sometimes they can be distinguished only with difficulty (by the ring surrounding them) from the segregations of troilite and nickel-iron.

Spicate (columnar) chondrules consist of one or several skeletal crystals of olivine. The most frequent width of the bars is 0.02 - 0.03 mm. A vitreous mass or rhombic pyroxene is found between these bars; in some chondrules the skeletal crystals from the edges of the chondrule are surrounded by tabular crystals of olivine, less often by crystals of rhombic pyroxene.

The fully crystalline granular chondrules are predominantly 1.2×0.7 mm in diameter. They consist of small grains of olivine and less often of rhombic /102 pyroxene. The shape of the grains is tabular. The size of the grains of rhombic pyroxene is larger in most cases than that of the olivine grains, so that the chondrules sometimes have a porphyritic structure.

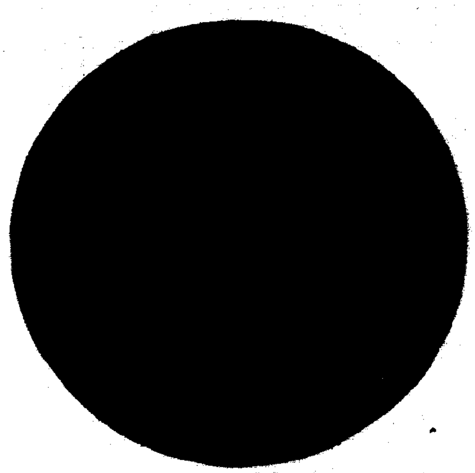

Fig.2 Chondrule of Eccentric-Radiate-Fibrous Structure and Pyroxene Composition. Gray variety of meteorite. Section No.62. Transmitted light. Without analyzer. $\times$ 35

Eccentric-radiate chondrules. Their structure is eccentric-radiate. The fibers composing the chondrules consist of rhombic pyroxene and range in thickness from lines hardly perceptible under the microscope to hundredths of a millimeter. The spaces between the fibers are filled with a vitreous or slightly crystalline mass, apparently likewise of enstatic composition. The shape of the chondrules is ellipsoidal, less often spherical (Figs.1 and 2). Their size ranges from 2 × 1.5 mm downward.

Fig.3 Chondrule of Porphyritic Structure
Black-vitreous mass. Light gray - olivine grains.
Gray variety of meteorite. Section No.62.
Transmitted light. Without analyzer. × 35

The section No.63 was found to contain a chondrule in the form of an elongated ellipse, one half with a uniform granular structure of olivine composition and the other of radiate-fibrous structure, consisting of rhombic pyroxene and clinopyroxene.

Porphyritic chondrules. These chondrules consist of grains of olivine of prismatic and tabular form, 0.1 - 0.3 mm in size, included in a vitreous or weakly crystalline mass, probably of pyroxene composition (Fig.3). The mean dimensions of the chondrules are 1.5 × 0.8 mm.

Vitreous chondrules. One chondrule of almost regular spherical form, /103
0.3 mm in size, was found in the black variety of the meteorite. Its structure was vitreous, and in certain regions the glass was devitrified.

Fragments of chondrules with well-preserved structure are also encountered in the interior of the meteorite.

TABLE 1

QUANTITATIVE RELATIONSHIP OF MINERALS IN THE VARIETIES OF THE SEVRYUK METEORITE, IN VOLUME PERCENT

Type of Mineral	Varieties	
	Gray	Black
Silicate portion (olivine, pyroxene, and others)	91.3	91.3
Nickel-iron	4.0	4.4
Troilite	1.4	0.3
Dustlike grains of troilite and iron smaller than 10 μ	-	2.2
Troilite in fine accretions with nickel-free iron	3.0	1.0
Troilite partially converted into iocite	-	0.6
Chromite	0.3	0.2
Total	100.0	100.0
Area of polished sections measured	280 mm^2	290 mm^2

The content of ore (opaque) minerals, troilite and nickel-iron, in the chondrules is lower than in the meteorite as a whole and amounts to only tenths of a percent.

An elevated content of magnomagnetite is observed in the vitreous mass of some chondrules, at almost complete absence of troilite and nickel-iron.

3. Quantitative Mineralogical Composition of the Meteorite

Under the microscope, the following minerals were found in the meteorite:

olivine, rhombic pyroxene, clinopyroxene, vitreous mass (mostly of pyroxenic composition), nickel-iron, native nickel-free iron, troilite, chromite, magnetite, magnomagnetite, and ilmenite.

An estimate of the quantitative content of minerals, made by the linear method in reflected light, gave a different content for certain minerals in the gray and black varieties of the meteorite. The percentage of a mineral like magnetite reaches 0.6 in the black variety (Table 1); in the gray and light gray varieties of the meteorite, magnetite is found only in rare isolated grains (amounting to less than a hundredth of a percent). Troilite and, in part, iron are found in the finely divided dust state in the black variety of the meteorite. It can be seen from Table 1 that the content of dustlike troilite and nickel-iron particles smaller than 10 mm is 2.2% by volume.

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Fig.4 Graphic Structure of Accretion of Native Iron (White) with Troilite (Light Gray) Along the edges (dark gray), iocite. Gray variety of the meteorite. Oil immersion. Reflected light. × 1250

The presence of native iron in fine accretions with troilite should be noted. This was shown to be entirely free of nickel.

Ilmenite, a very rare mineral in meteorites, is observed in the form of single grains in all three varieties of the Sevryuk meteorite.

4. Microscopic Description of the Minerals

Troilite. In the gray and light gray varieties of the meteorite, troilite forms relatively coarse segregations ranging in size from hundredths of a millimeter to 0.5 mm. Large segregations of troilite are considerably less frequent in the black variety of the meteorites. Usually, their shape is irregular, at times with veined branches. Under polarized light a finely granular structure

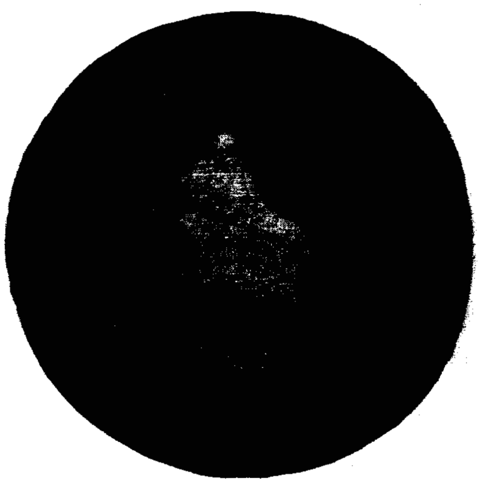

Fig.5 Troilite Accretion with Native Iron (Marginal Part) and (at the Center) Continuous Segregation of Native Iron Light gray variety of the meteorite. Reflected light. × 108

is observed in troilite, with grains hundredths and thousandths of a millimeter in size. In some coarse segregations, however, a peculiar concretionary structure of troilite with native iron is observed, the grains of both minerals having the same shape and a size in thousandths of a millimeter. In other regions this concretionary structure resembles a graphic texture, with the troilite having an elongated and, occasionally, vermicular shape whose grains are several microns in size and appear as though embedded in the native iron (Fig.4). Sometimes such structures are observed in the peripheral parts of the segregations, whose center contains a monomineralic formation consisting of troilite or nickel-iron (Fig.5).

It is very interesting to note that sometimes the accretions of native iron have a magnetite fringe (mantle) several microns thick (Fig.4) with distinct iron faces, which is not observed in the accretions of troilite and nickel-iron without fringes.

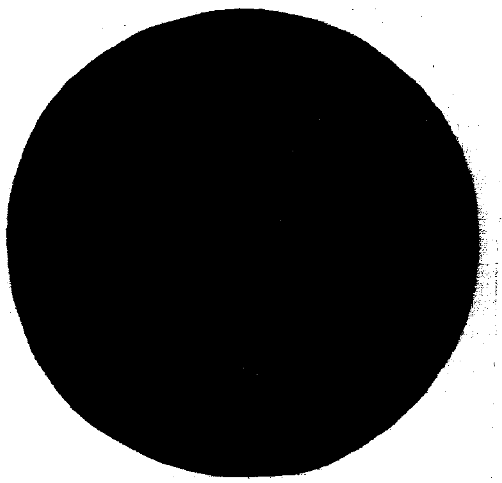

Fig.6 Dustlike Grains of Troilite
Black variety of meteorite. Reflected light. Oil immersion. × 1250

Small grains of troilite, in most cases dustlike, predominate in the black variety of the meteorite (Fig.6). These extremely minute formations, of isometric and, occasionally, of oval shape, are embedded in the silicate portion of the meteorite, forming "densely distributed regions" tenths of a millimeter in size. They often mantle grains of olivine, pyroxene, and chromite. These /105
dustlike grains are tenths of a micron in size, and rarely reach several microns.

Troilite veins, ranging in width from 1 - 2 microns to tenths of a micron, and several microns in length (cf. Fig.10) occur rather often in the black variety of the meteorite. They occur in the form of straight lines or of meandering curves.

Fig.7 Neumann Lines (?) of Nickel-Iron
Gray variety of meteorite. Oil
immersion. Reflected light. × 1250

Often, especially in the black variety of the meteorite, one encounters troilite segregations of spherical form (globular), hundredths or thousandths of a millimeter in size. In some places they have a slightly elongated shape. Inclusions of extremely minute droplike segregations of nickel-iron are observed in some troilite spherules.

Nickel-iron, represented by taenite and kamacite, is encountered in small quantities in the meteorite. Its mean content is about 4% by volume. It is usually the same in shape and size as troilite, and is sometimes concreted with it. In some segregations of nickel-iron, Neumann lines are observed at high magnifications in oil immersion (Fig.7).

In the black variety of the meteorite, and less often in the gray variety, segregations of nickel-iron are completely (or sometimes only partially) substituted by magnetite, with the formation of a corrosion structure (Fig.8). In rare cases, the black variety of the meteorite exhibits regions with scattered droplike segregations (globules) of nickel-iron (Fig.9).

Native nickel-free iron. Besides taenite and kamacite, native iron is also found in the Sevryuk meteorite. This native iron is entirely free of nickel and forms a fine, and sometimes a graphic, concretionary structure with the troilite (Fig.4).

Fig.8 Corrosion Structure of Substitution of Iron (White) by Iocite (Gray)
Black variety of meteorite. Reflected light. × 500

Some segregations with such a texture have partly been transformed, along the edges, into magnetite; however, there are also accretions in which the native iron has been completely replaced by magnetite, while the troilite grains have persisted; in that case the components of the graphic texture are troilite and magnetite.

The diagnostic signs for native iron are for the most part similar to those of nickel-iron. /106

A chemical microanalysis of the above segregations for the presence of nickel, made by the author, yielded negative results. The same microchemical tests were repeatedly made by A.P.Nasedkin and likewise proved the absence of nickel in the iron and troilite forming aggregates with a fine concretionary texture.

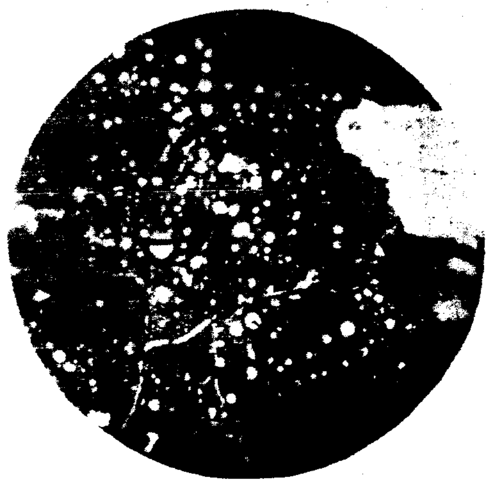

Fig.9 Small **Spherules** of Nickel-Iron
Gray variety of meteorite.
Reflected light. × 500

Magnomagnetite (?). This mineral is observed in the form of sparse grains in all three varieties of the meteorite. The grains are usually encountered exclusively in the vitreous mass and have an irregular rounded and less often octahedral shape.

Iocite. This was formerly taken by me as a mineral of magnetite; it is encountered in all three varieties of the meteorites, but in the greatest quantity in the black variety (sometimes as much as 0.6% vol.%).

Iocite is almost always observed in association with iron and troilite, from which it was formed by oxidative processes. In the black variety of the meteorite, there are segregations of iron more than two thirds of which have been transformed into iocite, thus forming aggregates with a peculiar corrosion structure of substitution (Fig.8).

In other cases, troilite and native iron in the marginal parts of the concretions have passed over into iocite, forming a fine shell up to several microns in thickness. The iocite in such segregations sometimes has the appearance of a single crystal with clearly defined faces (Fig.4).

Very rare extremely fine veinlets of iocite are found, with width up to one micron in the form of ramifications from larger segregations and veins of iocite.

In the section No.48, a veinlet of iocite about 2 μ in width was found (Fig.10). The veinlet passes through a chromite grain and through the extremely fine troilite veinlets it encounters, and can then be followed into segregations of troilite in a fine accretion with native iron; in places, the concretions have a graphic texture. Consequently, the formation of veinlets of iocitic composition took place at a later period than the formation of the chromite and troilite with the graphic texture. Iocite is determined in reflected light /107 from the following diagnostic indices: mineral of gray color; index of reflection $R \cong 16\%$; isotropic; no internal reflections noted. Diagnostic etching: $FeCl_3$ and $Cu(OH)_2$ - negative; HCl - positive, blackening of the mineral; HNO_3 - violent foaming noted.

Almost similar signs are exhibited by artificial FeO (wüstite).

Chromite. This is more or less uniformly distributed in all the varieties of the meteorite. Its average content is 0.3 vol.%. The chromite veins usually are of irregular shape and are hundredths of a millimeter in size. In the black variety of the meteorite, the chromite is often pierced by extremely fine veinlets of troilite (Fig.10), and sometimes it is mantled by the troilite along the periphery of the grain. In infrequent cases, small droplike inclusions of troilite are observed in the chromite.

Ilmenite. This is a very rare mineral. It is found in the meteorite in the form of single segregations or grains. Ilmenite is determined from the following signs: color brownish-gray, with a faint reddish-brown tinge in oil, index of reflection R = 17%, double reflection weak and strongly anisotropic, internal dark-brown reflections noted with oil immersion, great hardness, not scratched by steel needle. Diagnostic etching with the usual standard reagents is negative.

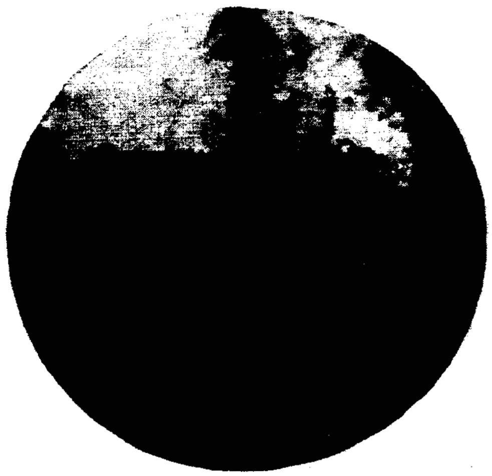

Fig.10 Iocite Veinlet
Black: chromite pierced by fine veinlets of troilite. White: native iron in fine accretions with troilite. Reflected light. Oil immersion. × 1250

The segregations of ilmenite found have an isometric form and are hundredths of a millimeter in size. The coarsest segregation is 0.1 mm in diameter and was found in the section No.48 of the gray variety. The segregation was embedded in the silicate portion and was surrounded by small granules of chromite. The ilmenite segregation has small droplike inclusions of troilite 3 - 5 microns in size, arranged in the form of a chain (Fig.11). The polished section shows a microgranular structure, with grain sizes up to several microns, in the segregation.

In the section No.49 of the black variety of the meteorite, the nickel-iron showed a segregation of ilmenite of hexahedral form, 0.07 mm in size, with minute inclusions of nickel-iron (Fig.12).

Olivine. This occurs most frequently in the groundmass of the meteorite, cementing the chondrules, and also forms the entire mass of the chondrules or a part of it. Olivine is observed in the form of discrete inclusions in the troilite and nickel-iron.

In the interstitial mass, the olivine grains have a tabular, lenticular, or prismatic shape; their average size is in hundredths of a millimeter. Sometimes minute grains of olivines are included in the enstatite crystallites. In some regions there is a weakly crystallized vitreous mass between the olivine grains, apparently of enstatic composition (or maskelynite). In the form of in- /108

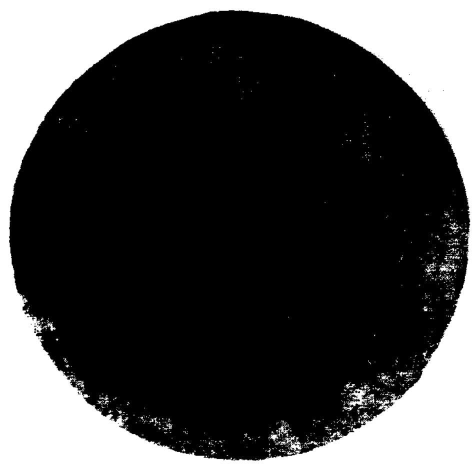

Fig.11 Segregation of Ilmenite (Il)
White: troilite. Gray: silicates.
Light gray variety of the meteorite.
Reflected light. × 167

clusions in the olivine grains, we found nickel-iron, troilite, and, infrequently, chromite. The olivine crystals are colorless.

Rhombic pyroxene. This, like olivine, enters into the composition of the groundmass of the meteorite and into the composition of the chondrules. It most often forms radiate chondrules and is of subordinate importance in the other chondrules. In transmitted light, it is colorless and shows a distinctly shagreen surface, characteristic of this mineral.

Clinopyroxene. This is found in the form of sparse grains of prismatic shape, 0.15 - 0.05 mm in size. In places, its crystals are finely and polysynthetically twinned. Minute inclusions of olivine grains, hundredths of a millimeter in size, are encountered here. The extinction angle of clinopyroxene is 24°. Clinopyroxene is occasionally found in chondrules, associated with rhombic pyroxene.

Fig.12 Grain of Ilmenite (Gray) of Hexahedral Form
White: nickel-iron. Black variety of meteorite.
Reflected light. × 500

Vitreous mass. This is found to a considerable extent in the meteorite; estimated in the section No.48 (gray variety of the meteorite), the content of vitreous mass is 7 - 8 vol.%.

The regions composing the vitreous mass are clearly visible in the polished sections under reflected light. The vitreous mass is usually observed in the form of small regions in the black variety and in the form of larger regions in the light gray. The size of these zones is in general hundredths of a millimeter. In the interstitial mass between the chondrules, vitreous matter is most often observed between the grains of olivine and pyroxene. Such regions take on a mesh structure. In some regions of this structure, there are extremely minute inclusions of the minerals troilite, nickel-iron, and magnomagnetite. Vitreous zones have been found in which the content of magnomagnetite in the form of dustlike grains is as large as several percent. Besides that, minute grains of olivines and pyroxene are also often met in the vitreous mass. The vitreous mass has also been found in chondrule in the form of extremely minute regions between grains of olivine or pyroxene.

5. Conclusion /109

The Sevryuk meteorite, consisting of three varieties, gray, light-gray and black, is composed mainly of olivine, pyroxene, and vitreous mass. In smaller quantities, also nickel-iron, troilite and chromite are encountered.

Isolated grains and segregations of iocite, ilmenite, and native nickel-free iron are found in the meteorite. In the gray variety, less often in the black variety, aggregates of native irons and troilites have a thin lamellar concretionary structure and sometimes a graphic texture.

The black variety of the meteorite contains iron and troilite, mainly in the form of fine veinlets, in the dust state, etc. In addition, some of the iron in this variety of the meteorite has been substituted by iocite. In the gray varieties, the aggregates with a fine concretionary structure of troilite and nickel-iron have an iocite mantle in rare cases.

The presence of the mineral iocite in the meteorite indicates that the meteorites were subjected to thermal metamorphism. On the basis of the structural and textural features and of the mineralogical compositions, it should be postulated that the black and gray varieties of the meteorite are modifications of the light gray variety. The black and gray color of the varieties is evidently due to the presence of finely divided iocite, troilite, and nickel-iron. It should also be noted that iocite, which is extremely rare on earth (e.g. in the lavas of Vesuvius), was found for the first time in the Sevryuk meteorite as a secondary mineral formed from the iron by thermal alteration. Likewise for the first time, segregations with a fine concretionary structure of troilite and nickel-free native iron are encountered.

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